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Proposed Ground-Based Control of Accelerometer on Space Station Freedom

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PROPOSED GROUND-BASED CONTROL OF ACCELEROMETER ON SPACE STATION FREEDOM

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ABSTRACT

This paper describes the innovative control of an accelerometer to support the needs of the scientists operating science experiments that are on-board Space Station Freedom. Accelerometers in support of science experiments on the shuttle have typically been "passive," record-only devices that present data only after the mission or that present limited data to the crew or ground operators during the mission.

With the advent of science experiment operations on Freedom, the principal investigators will need microgravity acceleration data during, as well as after, experiment operations. Because their data requirements may change during the experiment operations, the principal investigators will be allocated some control of accelerometer parameters. This paper summarizes the general-purpose Space Acceleration Measurement System (SAMS) operation that supports experiments on the shuttle and describes the control of the SAMS for Space Station Freedom. Emphasis is placed on the proposed ground-based control of the accelerometer by the principal investigators.

BACKGROUND

The Microgravity Science and Applications Division (MSAD) of the Office of Space Sciences and Applications (OSSA) at NASA Headquarters sponsors science experiments flown on shuttle missions. OSSA also sponsors dedicated microgravity science shuttle missions featuring numerous microgravity science experiments in the middeck and Spacelab. These microgravity missions typically have a duration of 7 to 14 days with the shuttle attitude and control optimized to minimize acceleration disturbances for the science experiments on-board.

To support the individual microgravity science experiments and the microgravity missions, the Space Acceleration Measurement System (SAMS) project at NASA Lewis Research Center developed two styles of microgravity accelerometers, one for the shuttle middeck and Spacelab module and one for the Spacelab MPESS-B carrier in the cargo bay. (1, 2) A SAMS accelerometer measures the low levels of accelerations experienced by an experiment and records the data on optical data disks. The data are later converted to engineering units and presented to the principal investigator (PI) associated with the experiment.

Four original SAMS units were built for operation in the shuttle middeck and Spacelab module. With this style unit, the crew interaction is limited to power on and off, data record on and off, changing data disks, and manual reset. During a mission, the majority of crew time with SAMS is typically spent changing disks. The acceleration is not displayed for the crew, and the data are not down-linked to the Payload Operations Control Center (POCC).

For the two SAMS units built for operation in the shuttle cargo bay, acceleration data are also recorded on optical data disks, but these disks are inaccessible to the crew. Some of the data for these units may be down-linked to the POCC for observation by scientists during experiment operations. For this style unit, the POCC and crew interaction is limited to power on and off, and data record on and off.

For both styles of units, up to three remote triaxial sensors are installed in, on, or near the experiment apparatus. These sensors are each connected by an umbilical cable to the SAMS main unit.

For a particular mission, the data-acquisition algorithms and the remote triaxial sensor head locations are selected in consultation with the PI's, the experiment hardware developers, the mission manager's office, and MSAD. The data-acquisition algorithm establishes several parameters for the SAMS unit, such as the number of sensor heads, the sensitivity of the sensor heads, the data sampling rate, and the frequency response of the sensor heads. The sensor locations establish the lengths of the umbilical cables. These parameters are established about 18 months prior to final delivery of the SAMS unit to Kennedy Space Center for shuttle integration.

The data acquired during the mission is later converted to engineering units and processed to compensate for bias and temperature effects. The acceleration data is available to the PI's approximately 1 to 2 months after the mission is completed. With the cargo bay style of SAMS unit, the down-linked data is available during the mission in the POCC. This data may be processed and displayed at the POCC during the experiment operations.

The next-generation SAMS microgravity accelerometer is currently being designed to support science experiments on Space Station Freedom. The design effort will benefit from the experiences involved in design, fabrication, and operation of the SAMS units for the shuttle microgravity science missions. This new SAMS unit (SAMS-SSF) will also avail itself of many of Freedom's features to enhance both its operation and the data provided to the PI's. The SAMS on Freedom will allow more sensors, on-board data processing, and near-real-time data displays, and more PI control of its operation and data display.

ACCELEROMETER DESCRIPTION

The experiments on-board Freedom will initially be operated during the time that Freedom is ground-tended. This will require untended operation for (nominally) 45 days between crew visits. Even though Freedom will eventually be staffed with crew full-time, the SAMS-SSF should not require a significant amount of crew resources. To accomplish this, the SAMS-SSF will be designed for ground-based PI control of PI-dependent parameters (Figure 1). The PI's will have acceleration data displayed in their local experiment operation control centers. They will also have control of SAMS-SSF parameters, as required, from their control centers.

The SAMS-SSF will have remote sensors mounted in, on, or near experiment apparatus, similar to the SAMS units operating on the shuttle. The conceptual installation of the SAMS-SSF is shown in Figure 2. The SAMS-SSF main enclosure and the remote sensors will be connected by Freedom's Data Management System (DMS) instead of the dedicated cables used on the shuttle. This connectivity will allow the SAMS-SSF to be easily reconfigured with sensors when experiments and racks are exchanged with new experiments and racks brought up to Freedom. Generally, the sensors will be installed in the experiment racks on the ground before they are taken to the Space Station Freedom.

In contrast to the current SAMS design, the SAMS-SSF will be able to use more than three sensors. It will be possible to install a sensor head on those experiments that need one instead of compromising in deference to the three top-priority experiments, resulting in better support to the PI's.

The SAMS-SSF will address the two main problems identified from the SAMS units on the shuttle, namely, the very limited or nonexistent access to data during experiment operations, and the lack of interactive control of data acquisition and processing.

For SAMS-SSF, acceleration measurement parameters will be adjustable to meet the needs of the PI's. The PI's will be able to modify the frequency band(s), the attendant sampling rate, data processing, and data recording (within technical, schedular, and budgetary limits).

The SAMS-SSF will incorporate on-board data processing to better serve the PI's, reduce the required down-link resources, enable crew display of microgravity environment, and reduce the mass storage requirements. The remote triaxial sensors sense the accelerations experienced by the experiment; then they pass these data via the Data Management System (DMS) to the main enclosure where the data are processed, stored, and prepared for down-linking. The data to be down-linked to the ground control center are sent from the SAMS-SSF to the Space Station Freedom communications and tracking subsystem via the DMS.

The various components of the SAMS-SSF system form building blocks which, with certain limitations, can be interconnected and "programmed" by the PI to form the required data path to the data storage and display, both on the ground and on Freedom. Several examples of data treatment are shown in Figure 3. The top data path illustrates the sensor A data processed into a power spectral density versus time data set that is recorded in mass storage and sent to the Freedom crew display. The next data path shows sensor B data processed by a low-pass filter. The filtered data are then recorded in mass memory storage. The same sensor B data are band-pass filtered and down-linked to the PI at the ground control center. In the two bottom data path, sensor A data are also processed into an acceleration magnitude versus frequency versus time plot that is down-linked to the ground control center. The sensor A data are also recorded directly in mass memory storage.

PRINCIPAL INVESTIGATOR INTERACTIVE CONTROL

Some of the SAMS-SSF parameters are allocated to the PI's to control and utilize. Resources such as data-recording capacity, down-link capacity, sampling rate, and frequency response will be allocated to the PI's.

Data

Many of the PI's need to access the acceleration environment data as soon as possible during their experiment operation so that they can make adjustments based on the microgravity environment. However, it will probably not be possible to down-link the data for all experiments in near-real-time. In addition, different types of experiments respond in vastly different time frames to disturbances, (e.g., the quick response time of a cryogenic fluid experiment compared with the long response time of a fluid diffusion experiment). Also, depending on the experiment design, the experiments typically have differing abilities to react and adapt to the environment. All these factors affect the acceptable delay between acceleration data acquisition and display of the data to the PI's.

The PI's will need to have the data displayed in differing formats depending on how the acceleration environment affects the experiments. Figures 4 to 7 illustrate the typical displays available to the PI's. For a more complete reference on the calculations involved and the interpretation of these displays, there are several good references available. (3 to 7)

Figure 4 illustrates the basic plot of acceleration magnitude versus time for a given interval of time. This plot is calculated from the acquired raw data with compensations for temperature effects, scale factor nonlinearity, misalignment of axes, and other factors. Such an acceleration plot may give some interpretive information, such as maximum and minimum values of acceleration, average level of acceleration, and the general characteristics of the environment. This display is convenient for picking out the maximum acceleration value within a time window and flagging it on the display.

Figure 5 illustrates the basic plot of vector magnitude versus frequency for a given interval of time. This plot presents information about the frequency distribution of the accelerations.

Figure 6 illustrates the basic plot of resultant vector (three-axis) power spectral density versus frequency for a given interval of time. This plot presents information about the frequency distribution of the acceleration energy at different frequencies. This information is of value to some PI's whose experiments are particularly sensitive or susceptible to accelerations at certain frequencies, such as structural mode frequencies.

Figure 7 illustrates the basic plot of vector power spectral density versus frequency versus time for a given interval of time. This "three-dimensional" plot presents information about the frequency distribution of the acceleration energy at different frequencies over small time intervals over the time span of the plot. A color or gray scale represents the power spectral density magnitude over the spectrum shown in the legend. Features of interest, such as thruster firings (narrow vertical lines) and vehicle natural-resonant frequencies (horizontal lines), are easily seen in this type of display.

Control

With the acceleration data flow shown in Figure 3, the PI's may select one type of processing for the data to be recorded, another type of processing for the data displayed in the ground control center display terminal, and another type of processing to be displayed for the crew's use. The choice may be changed by manual or programmed command from the ground control center. A preliminary set of menus for use in the PI control of the SAMS-SSF is shown in Figures 8 to 14.

The PI in the control center can call up a control display (Figure 8) to configure the various data paths that he or she is entitled to change. A summary of the characteristics are shown in the display for reference. When a particular characteristic needs to be modified, the PI may select and change a functional block's characteristics. Figure 9 shows the sampling rate of the remote triaxial sensor being changed. The rate is being set to a 5X factor over the high-frequency response of the filter. Figure 10 illustrates changing the characteristics of the processor for the data to be stored in the on-board mass memory storage. In this case, the PI has selected 100 Hz for the high-frequency response. Figure 11 illustrates changing the type of data display currently on the control center display. In this case, the PI is selecting a "three-dimensional" power spectral density plot versus frequency and time.

Figure 12 shows the menu structure for setting the various parameters of a remote triaxial sensor. The check marks indicate the chosen feature. All the parameters shown are reasonable for an actual system with the exception of the notch filter frequencies that would be derived for the Freedom vehicle.

Figure 13 shows the menu structure for setting the various parameters of a data processor in the SAMS-SSF. Figure 14 shows the menu structure for setting the various parameters for a ground control center data display or a crew display.

Some of the experiments to be operated on-board Freedom may have some artificial intelligence in terms of experiment operation decision and direction. With such capabilities within an experiment, it may be possible for the experiment to automatically react to the changing microgravity environment by modifying the experiment operations. A two-way interface between SAMS-SSF and the experiment would be required. The experiment could automatically control the data-processing algorithm for the experiment's remote triaxial sensor data. Processed data could then be sent directly to the experiment for interpretation and reaction. Figure 15 illustrates the feedback nature of such an arrangement between SAMS-SSF and an experiment.

SUMMARY OF RESULTS

SAMS-SSF will be able to supply acceleration data to the Principal Investigators (PI's) in the form and time frame they desire. The PI's will be able to adjust the microgravity accelerometer operation in accordance with the observed results of the experiment. This will enable a more efficient implementation of microgravity experiments in space.

With the advent of sophisticated artificial intelligence within experiments, it may be possible for the microgravity acceleration data to become a part of the experiment's operation control loop.

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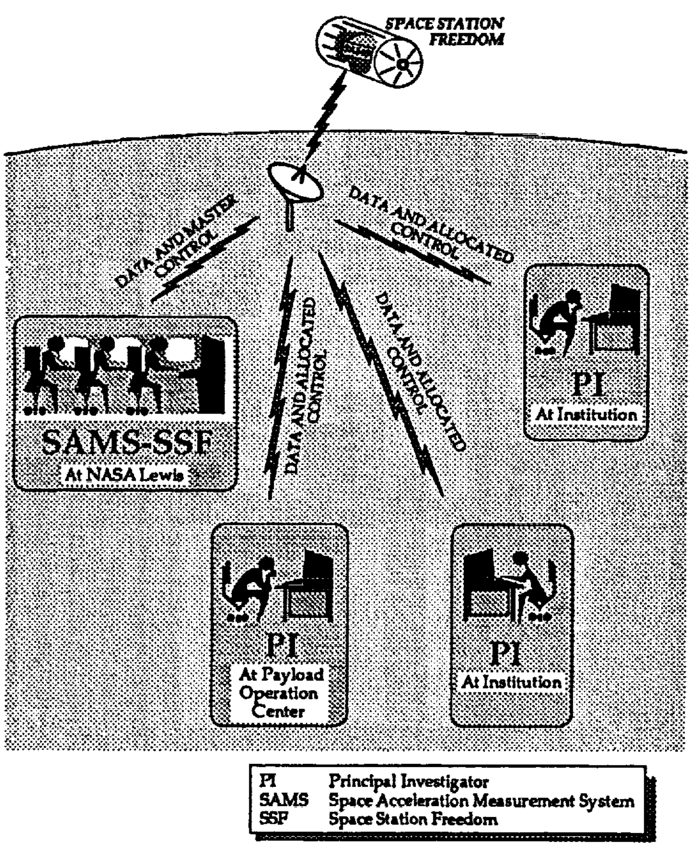

Figure 1.—SAMS Distributed Data and Control

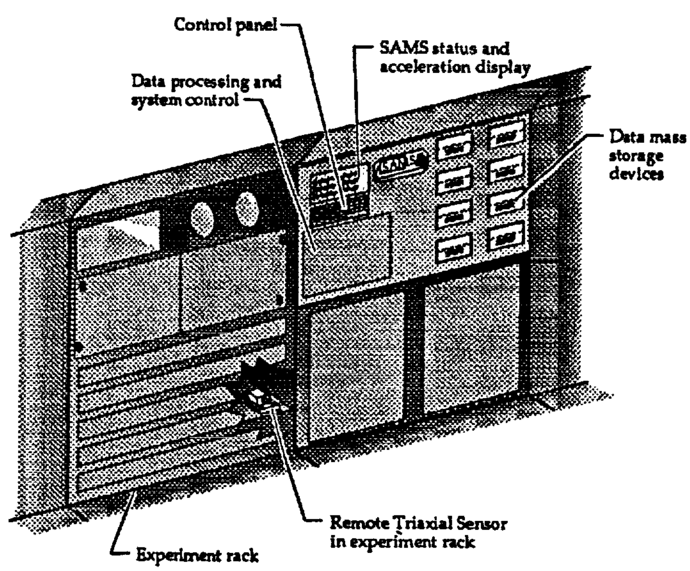

Figure 2.—SAMS and Remote Triaxial Sensor in Laboratory Module Racks

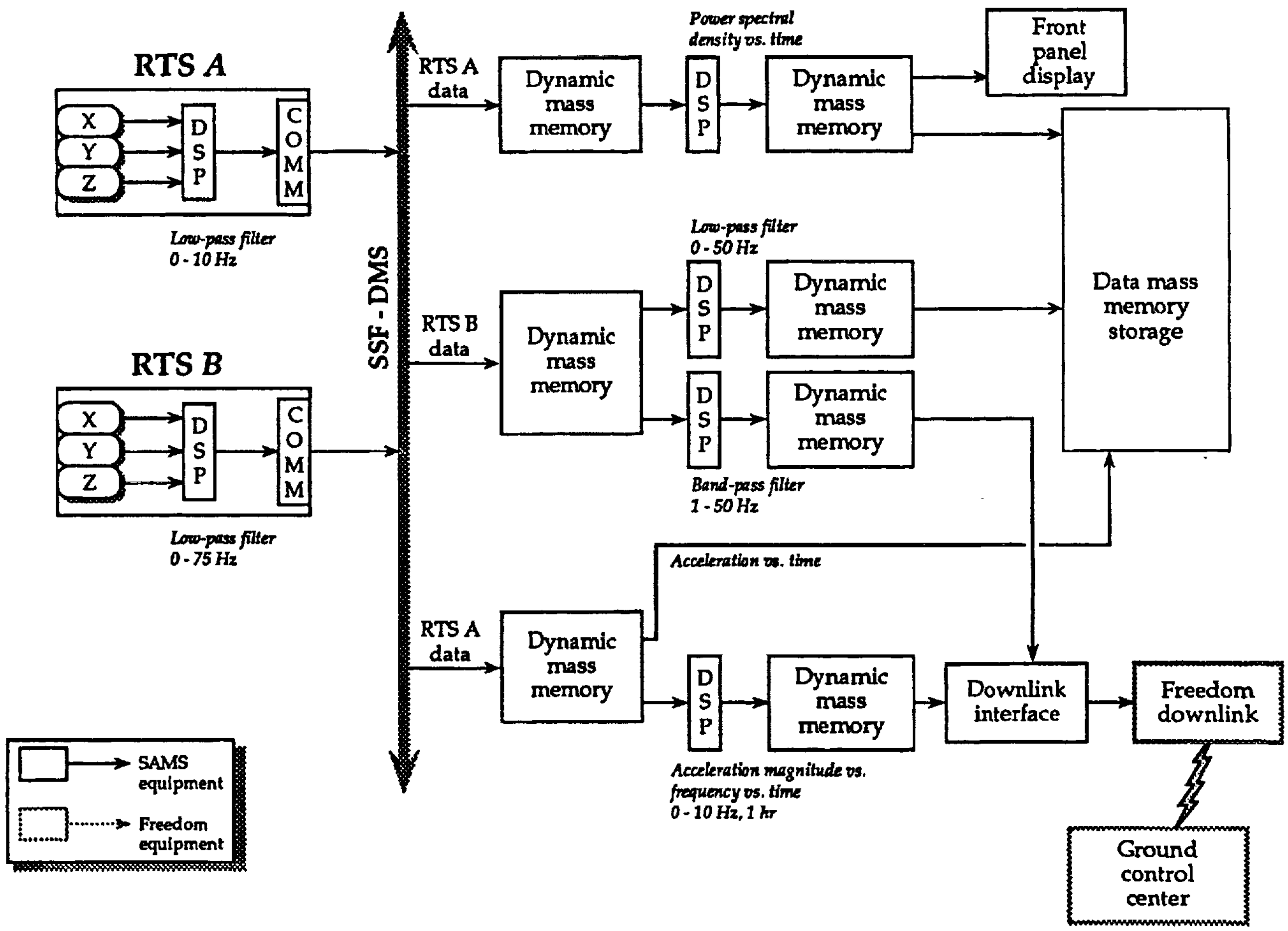

Figure 3.—Data Flow Options (Digital Signal Processing (DSP), Remote Triaxial Sensor (RTS))

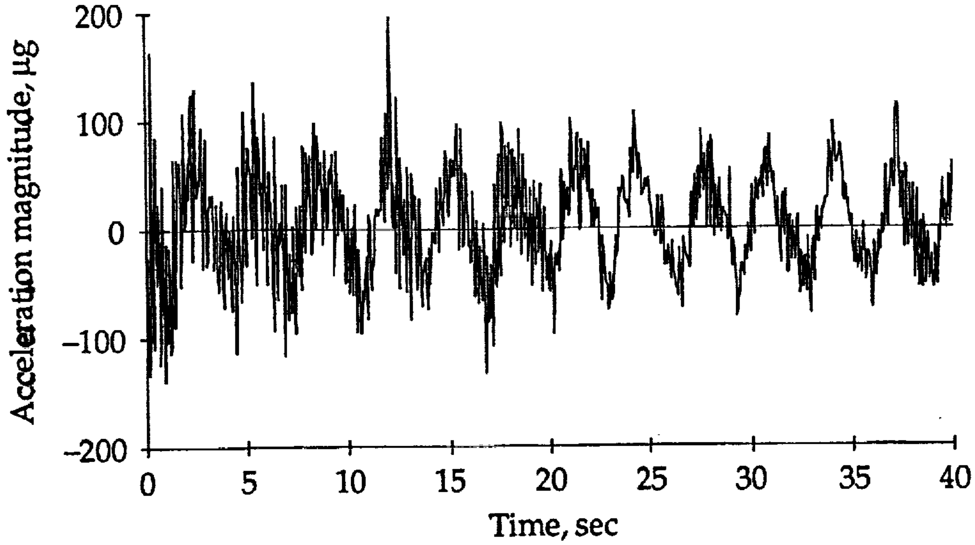

Figure 4.—Acceleration Magnitude (x-Axis) Versus Time

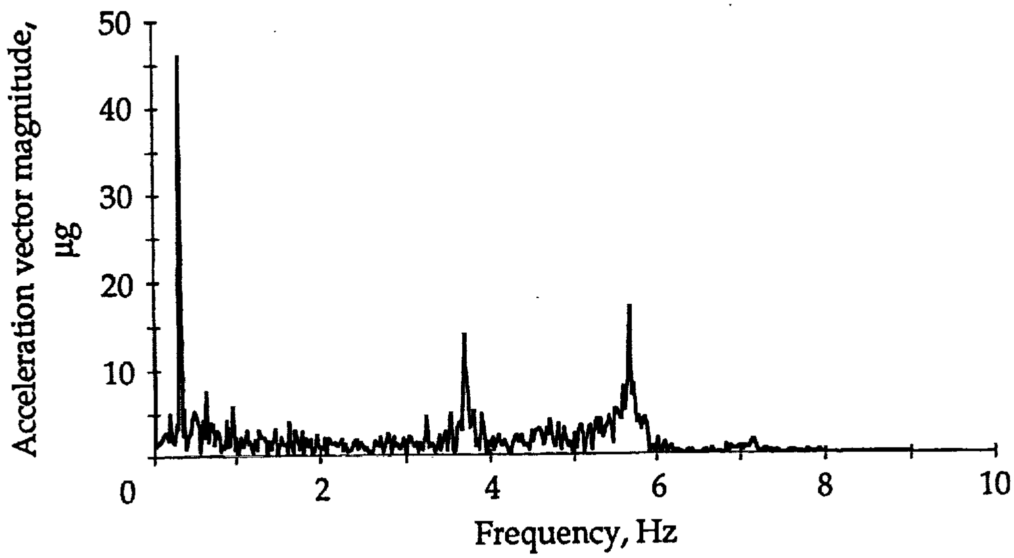

Figure 5.—Acceleration Vector Magnitude Versus Frequency

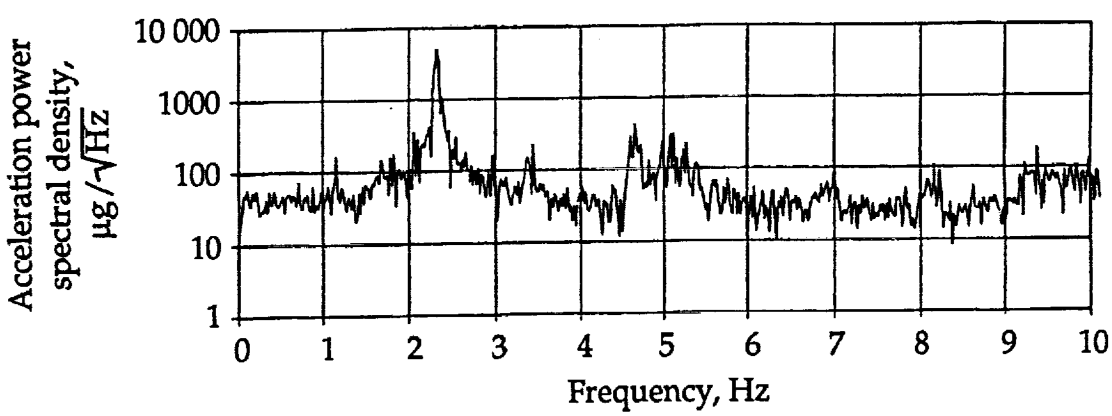

Figure 6.—Acceleration Power Spectral Density Versus Frequency (From Reference 3)

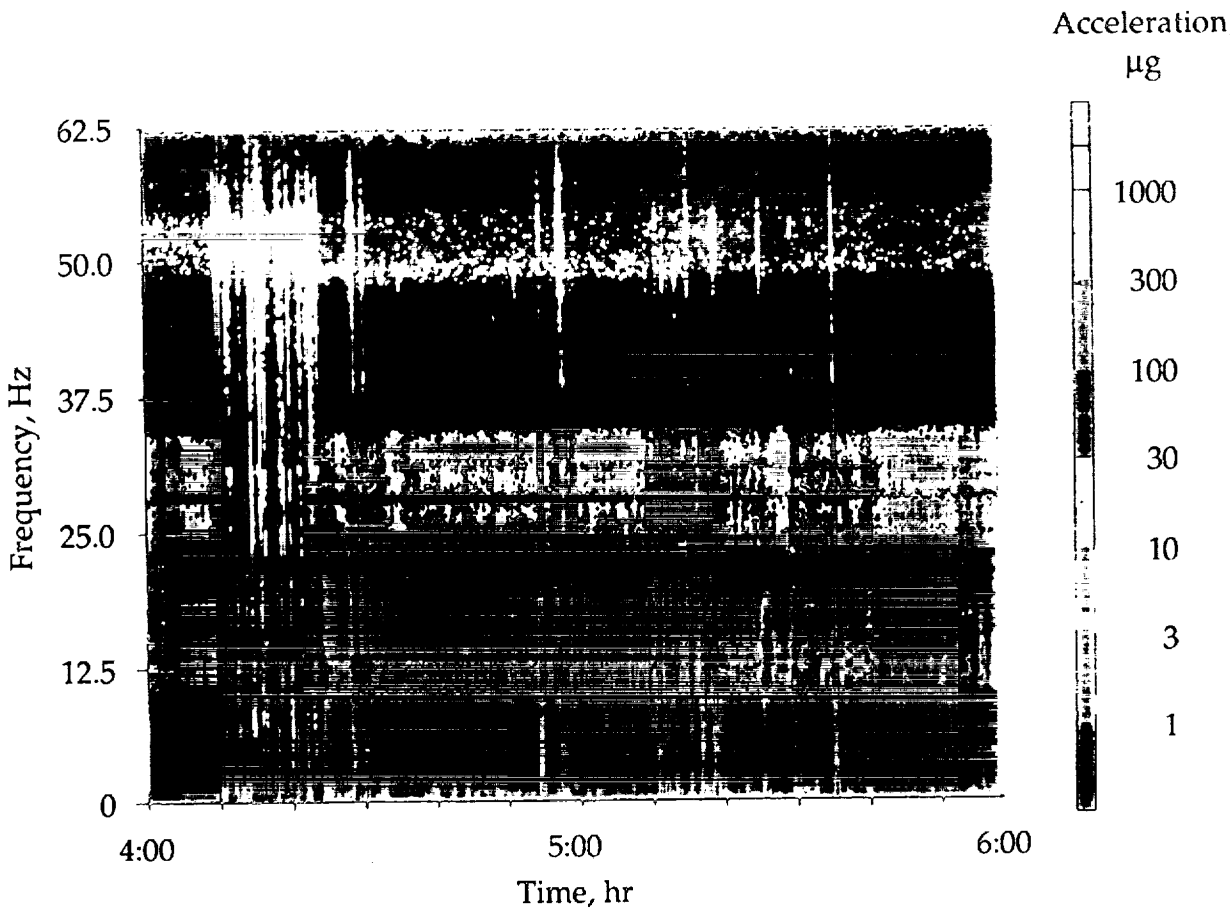

Figure 7.—Acceleration Power Spectral Density Versus Frequency Versus Time (From Reference 3)

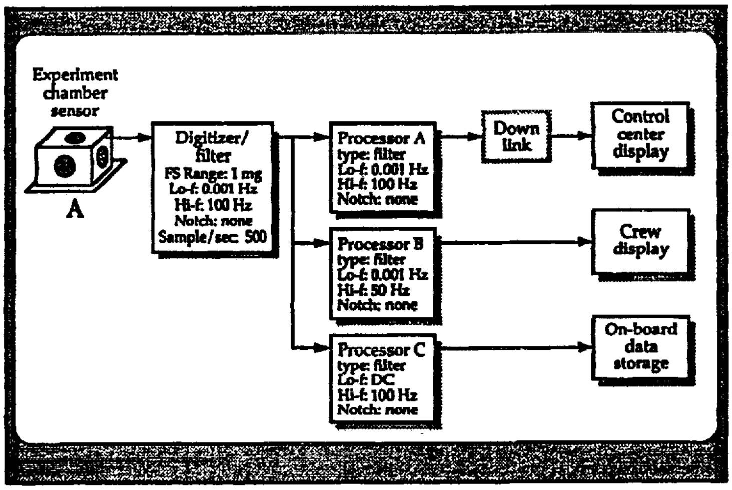

Figure 8.—Principal Investigator Display at Control Center Console

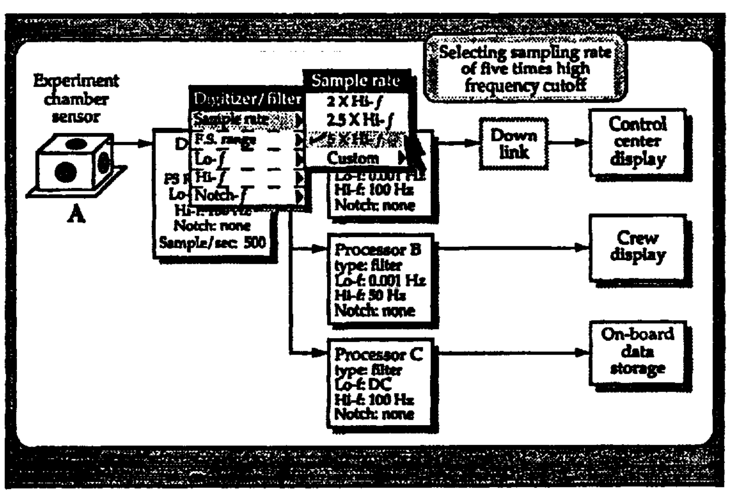

Figure 9.—Selection for Remote Triaxial Sensor Modification

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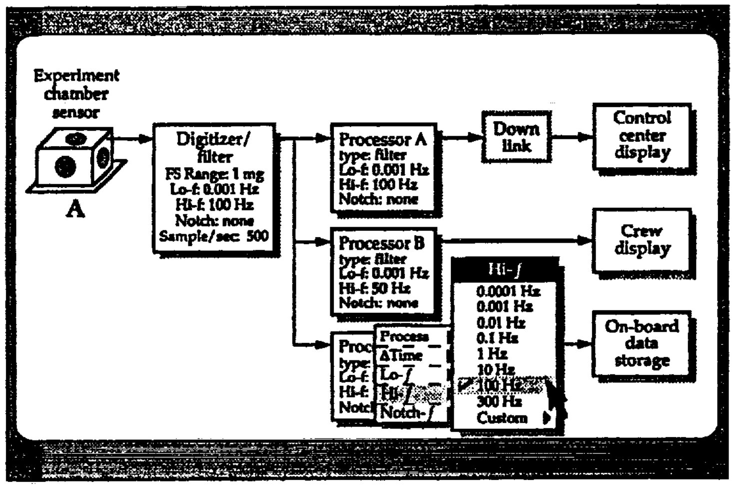

Figure 10.—Selection for Processor C Modification

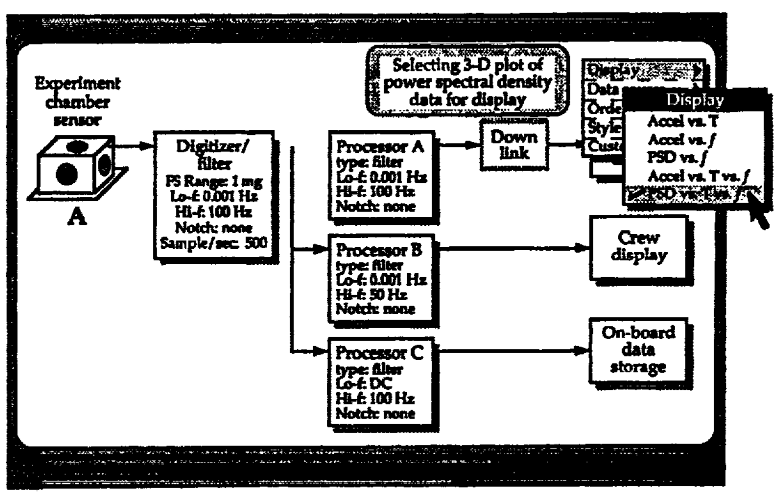

Figure 11.—Selection for Principal Investigator Data Display Modification

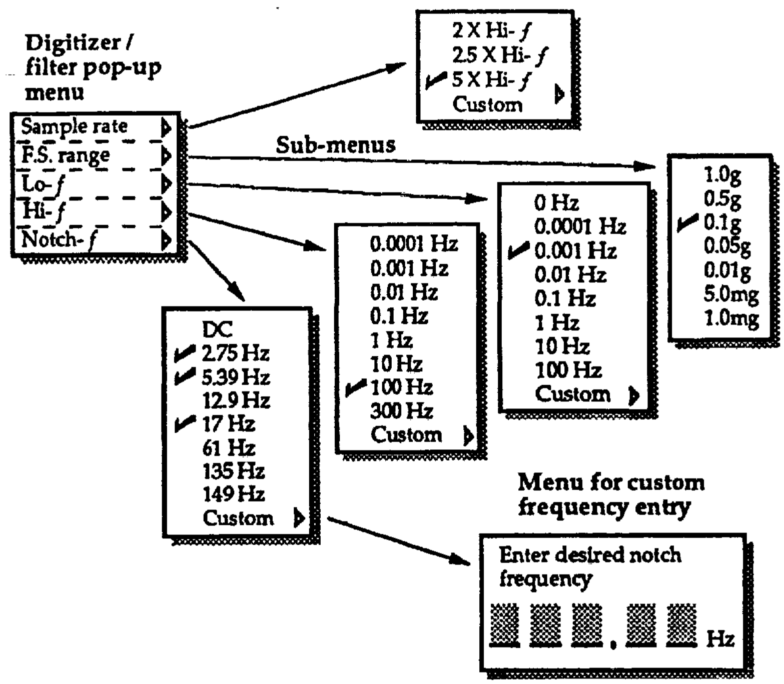

Figure 12.—Principal Investigator Control of Remote Triaxial Sensor

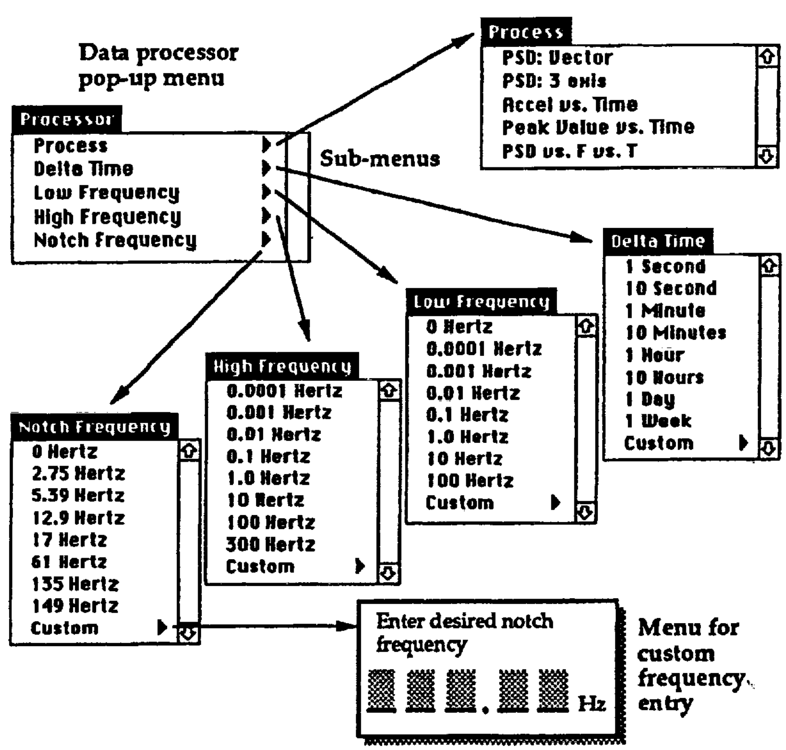

Figure 13.—Principal Investigator Control of Data Processor

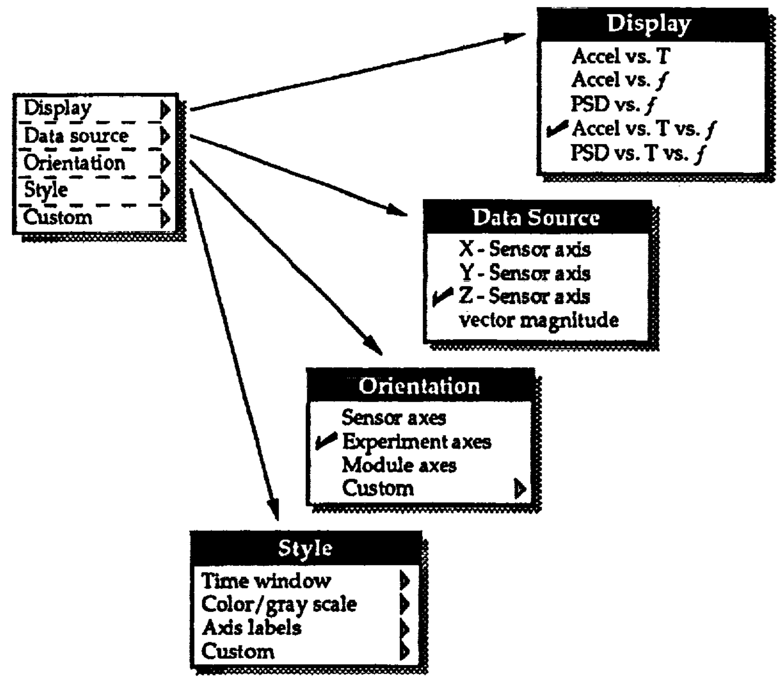

Figure 14.—Control Center Principal Investigator Data Display Menus

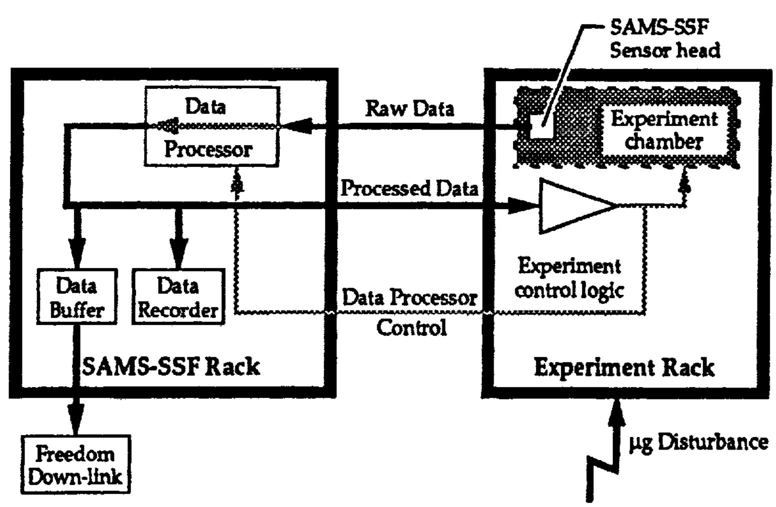

Figure 15.—Illustration of SAMS-SSF in Active Feedback With Experiment

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